

EDITED BY BILL TRAVIS &amp; ANNE WATSON SWAGER

# Low-cost LCDs implement bar-graph displays

SERGIO ZIGRAS, PARAMUS, NJ

You can easily implement LCD bar-graph displays in cost-sensitive designs by using widely available, low-cost, alphanumeric LCDs. Bar-graph displays indicate voltage, current, power, battery and fuel gauges, and sound level (in decibels), for example. The method uses a 16-character-by-one-line, 5×8-dot LCD. In general, all dot-matrix alphanumeric LCDs, such as one line by 16 characters or four lines by 20 characters, have identical features except for their size and dot-character parameters. These displays incorporate RAM (called the character-generator (CG) RAM) for eight user-defined characters.

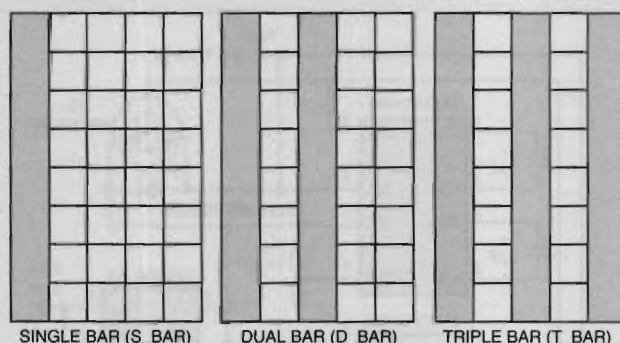
This bar-graph display (Figure 1) uses only 3 bytes, but you could use all 5 lines for better resolution. In that case, you would use 5 bytes of the available user RAM instead of 3, and the translating algorithm would become longer (Figure 2). Alternatively, you could use a two-line LCD: the top line for alphanumeric data and the second line for a bar-graph display. You can obtain the LCD initialization and support routines, as well as the user-defined character-generation methods, from the LCD manufacturer (such as Optrex Corp, Torrance, CA).

This example displays current in milliamps. It uses 48 bars (16 characters×3) and defines each bar to equal 3 mA. The total displayed current is  $48 \times 5 = 240$  mA. The variables and constants in the flowchart are MA for the current sample, S\_BAR for the single-bar byte, D\_BAR for the dual-bar byte, and T\_BAR for the triple-bar byte (Figure 2). These are the user-defined characters stored in the CG RAM. The 16-character counter is CNTR, the 15-unit parameter is UNIT\_15, the 10-unit parameter is UNIT\_10, and the five-unit parameter is UNIT\_5. These parameters represent 15, 10, and 5 mA. (DI #2078)

To Vote For This Design, Circle No. 309

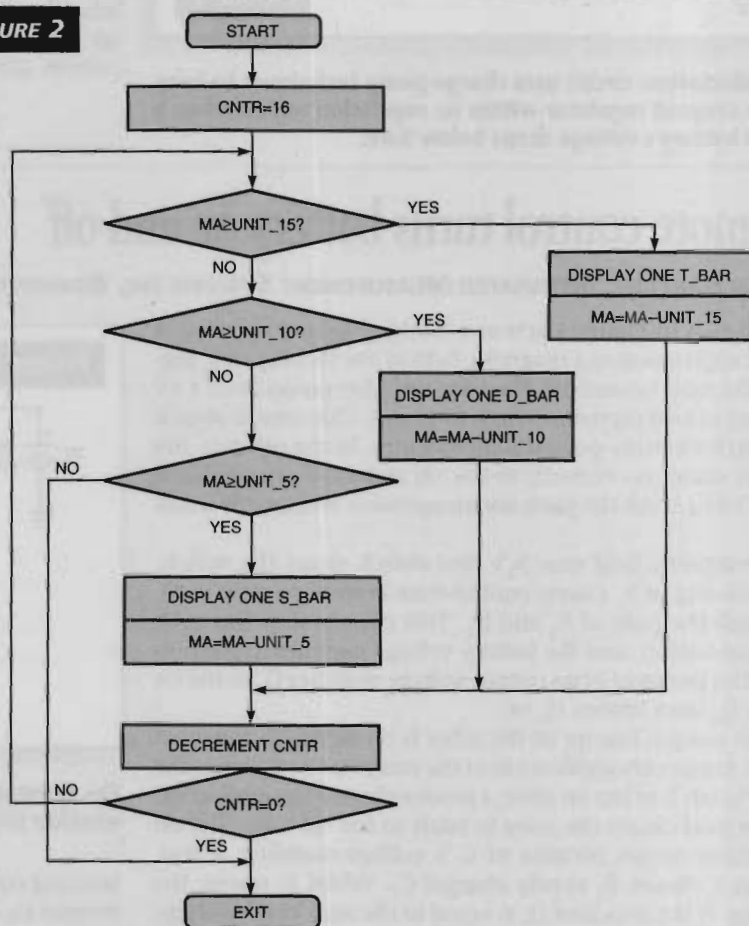
Using the algorithm in this flowchart, you can use an alphanumeric LCD's user-accessible RAM to implement a 0- to 240-mA bar-graph display.

FIGURE 1



Low-cost alphanumeric LCDs lead a dual life and make ideal elements for implementing bar-graph displays.

FIGURE 2



## Li-ion boost circuit uses no inductors

JOHN PARRY AND BILL MCINTYRE, NATIONAL SEMICONDUCTOR, GRASS VALLEY, CA

To maintain a regulated 3.3V supply for portable applications, most Li-ion batteries require a low-dropout (LDO) regulator and a dc/dc boost circuit. This need arises because the typical voltage range of a Li-ion battery is 4.2V (charged) to

2.5V (before recharge). The regulator alone suffices in the battery range of 4.2 to 3.5V, but below that level, the battery voltage needs boosting to keep the LDO IC in regulation. The circuit in Figure 1 senses the battery voltage via the  $R_1$ - $R_2$  resistor divider at comparator  $IC_2$ . The comparator turns off the converter when the battery voltage exceeds 3.6V.

When the converter is off, p-channel MOSFET  $Q_1$  is on, providing a low-impedance path from the battery to  $IC_3$ , the 3.3V LDO regulator. When the battery voltage drops below 3.6V, the comparator turns off  $Q_1$  and enables  $IC_1$ , a switched-capacitor converter that can supply 500 mA with no significant output-voltage drop. The 3.6V threshold (300 mV above the regulator's output voltage) allows for the output impedance of the converter and the dropout voltage of the regulator. This extra voltage ensures that the output voltage does not drop more than 5% from the target voltage at 50 mA.

Instead of using a common voltage doubler, the circuit uses a  $\frac{3}{2}$  voltage converter,  $IC_1$ , for improved efficiency. This 900-kHz charge pump switches capacitors  $C_1$  and  $C_2$  in two phases to create a voltage of  $\frac{3}{2} \times V_{BATT}$  at output  $V_{HIGH}$ .  $D_1$  is a Schottky diode that charges hold capacitor  $C_3$  during start-up. In normal operation, this diode conducts no significant current. (DI #2081)

EDN

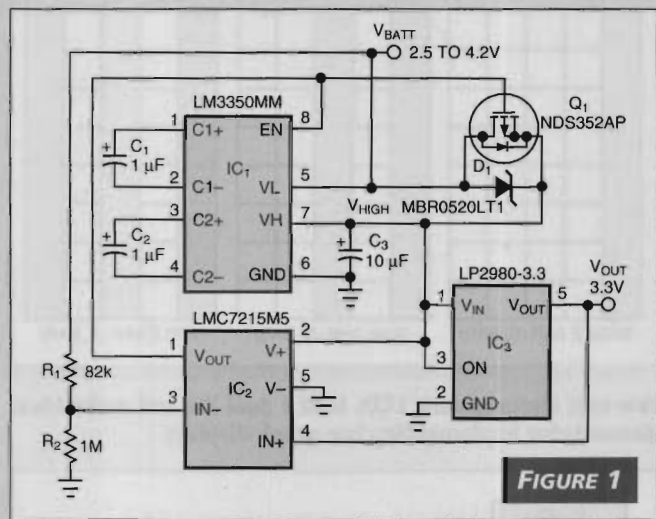


FIGURE 1

**An inductorless circuit uses charge-pump techniques to keep a low-dropout regulator within its regulation region when a Li-ion battery's voltage drops below 3.6V.**

To Vote For This Design, Circle No. 310

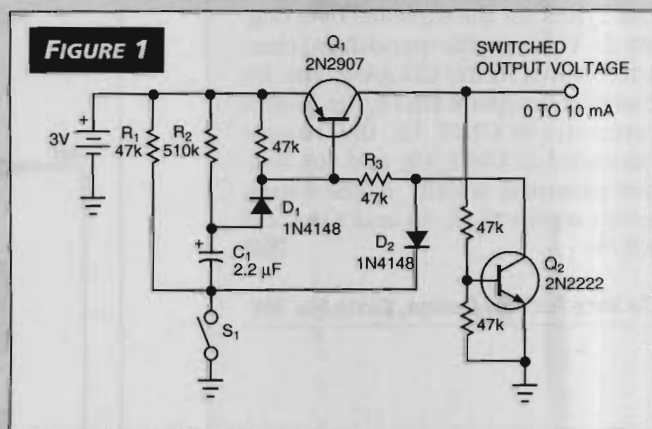
## Remote control turns battery on and off

ALLEN HARSTINE, INTEGRATED MEASUREMENT SYSTEMS INC, BEAVERTON, OR

The circuit in Figure 1 acts as a latching solid-state relay. A short application of a magnetic field in the vicinity of  $S_1$  toggles the relay on and off. The relay switches power from a 3V battery at load currents as high as 10 mA. This remote switch is ideal for battery-powered applications. In the off state, the circuit draws no current; in the on state, the circuit draws only 100  $\mu$ A. All the parts are inexpensive and readily available.

A magnetic field near  $S_1$ 's reed switch closes the switch. The closing of  $S_1$  causes emitter-base current to flow in  $Q_1$  through the path of  $R_3$  and  $D_2$ . This current flow forces  $Q_1$  into saturation, and the battery voltage switches to the output. The presence of an output voltage switches  $Q_2$  to the on state;  $Q_2$  then latches  $Q_1$  on.

The unique feature of the relay is its ability to toggle. A short, temporary application of the magnetic field causes the relay to latch to the on state; a greater-than-1-sec application of the field causes the relay to latch to the off state. The off switching occurs because of  $C_1$ 's voltage-doubling action. When  $S_1$  closes,  $R_2$  slowly charges  $C_1$ . When  $S_1$  opens, the voltage at the anode of  $D_1$  is equal to the sum of the voltage across  $C_1$  and the battery voltage (through  $R_1$ ).  $D_1$  conducts the resulting current to the base of  $Q_1$ , which overdrives the



**The duration of the magnetic field applied to  $S_1$  determines whether this relay circuit latches to the on or off state**

latching current from  $Q_2$  and turns off  $Q_1$ . Once  $Q_1$  is off,  $Q_2$  releases its latching signal. (DI #2074)

EDN

To Vote For This Design, Circle No. 311

# Current source forms unusually simple regulator

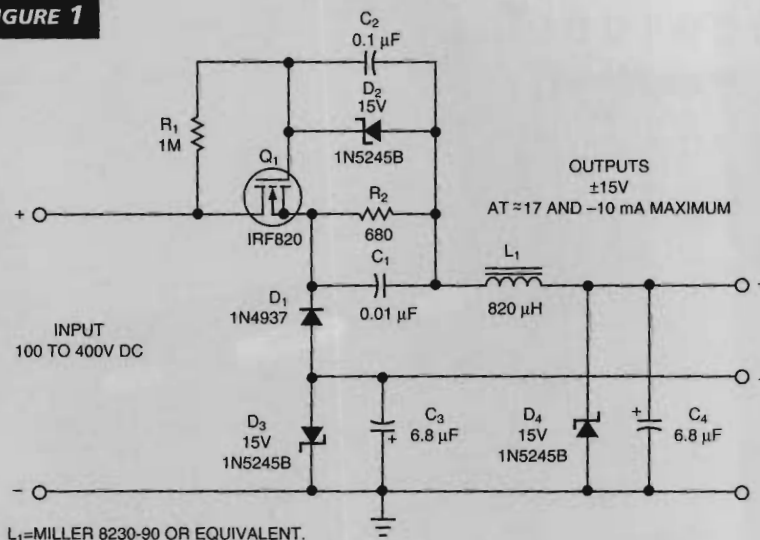
KENNAN HERRICK, ESI ELECTRONICS, SAN FRANCISCO, CA

A simple regulator uses a switching current source to drive a pair of shunt zener regulators (Figure 1). The circuit is a modification of the Design Idea "Simple regulator has one active part" (EDN, March 16, 1995, pg 44). At power-on, the small current through  $R_1$  raises  $Q_1$ 's gate voltage, thereby starting to turn on  $Q_1$ . Increasing current in  $L_1$  then creates a voltage drop in  $R_2$ , while  $L_1$ 's current charges  $C_4$  toward its ultimate 15V (set by  $D_4$ ). While these events are occurring,  $R_2$ 's voltage couples via  $C_2$  to  $Q_1$ 's gate, rapidly turning off  $Q_1$ . With  $Q_1$  fully turned off,  $L_1$ 's current continues to flow, now through  $D_1$  to charge  $C_3$ , for an ultimate voltage of -15V (set by  $D_3$ ) on  $C_3$ .

The resonant relationship of  $C_1$  and  $L_1$  causes the  $C_1$ - $L_1$  node voltage to start to decrease ( $C_1$  discharges); that decrease couples, as before, through  $C_2$  to  $Q_1$ 's gate.  $Q_1$  begins to turn on, and the cycle repeats.  $D_2$  would limit  $Q_1$ 's  $V_{GS}$  to 15V, although it never reaches that voltage because of the drop in  $R_2$ . The previous version of the circuit used an ordinary catch diode (1N4005) for  $D_1$ , because the diode's longer storage time served to square the oscillatory waveform. In this version, however,  $D_1$  must be faster to yield a reasonable output-current capability.

With no load, the efficiency of the circuit is zero, because shunt regulators  $D_3$  and  $D_4$  draw the full circuit current. The only other significant power-dissipating element is  $Q_1$ . At 150V input,  $Q_1$ 's voltage drop during the peak on-times (occupying approximately 10% of the duty cycle) is 4 to 6V. During the on-times,  $R_2$ 's drop is approximately 14V, so the instantaneous current is approximately 20 mA. The dissipation in  $Q_1$  is thus  $20 \text{ mA} \times 6 \text{ V} \times 10\%$ , or 12 mW. The regulator's approximate characteristics are a 170-kHz switching frequency, 300-nsec rise and fall times, and a 25% duty cycle.

FIGURE 1



**Simplicity and a low parts count reign in this high-voltage dc/dc converter. The circuit produces  $\pm 15\text{V}$  dual outputs, for total output power of approximately 400 mW.**

You can vary the voltages of  $D_3$  and  $D_4$  to obtain voltages higher or lower than 15V.

You can also reduce the value of  $R_2$  (but not by much;  $R_2$  parallels  $C_1$ ) to increase the output-current capability. With  $R_2=470\Omega$ , the available output currents are approximately -14 and 30 mA. With either current extreme,  $Q_1$ 's tab temperature does not exceed  $20^\circ\text{C}$  or so above ambient, so you need no heat sink.  $R_1$ 's rating must be commensurate with the input voltage. You can increase  $D_2$ 's voltage to approximately 20V to reduce  $Q_1$ 's forward drop. For reduced cost, you can use an IRF710 for  $Q_1$  if the input voltage does not exceed 350V. Finally, the circuit is short-circuit-proof. (DI #2077)

EDN

To Vote For This Design, Circle No. 312

## Wall-cube dc/dc converter is 85% efficient

STEVE PIETKIEWICZ, LINEAR TECHNOLOGY CORP, MILPITAS, CA

The ubiquitous 12V wall cube, power source of countless electronic products, generates an unregulated dc voltage of 8 to 18V, depending on line voltage and load. If you use a linear regulator to drop the voltage to 5V, a 400-mA load

translates to 5W worst-case dissipation in the regulator. To deal with the heat, you must provide adequate heat sinking, thereby increasing your product's size and weight. Moreover, customers may object to the heat. These factors can negate

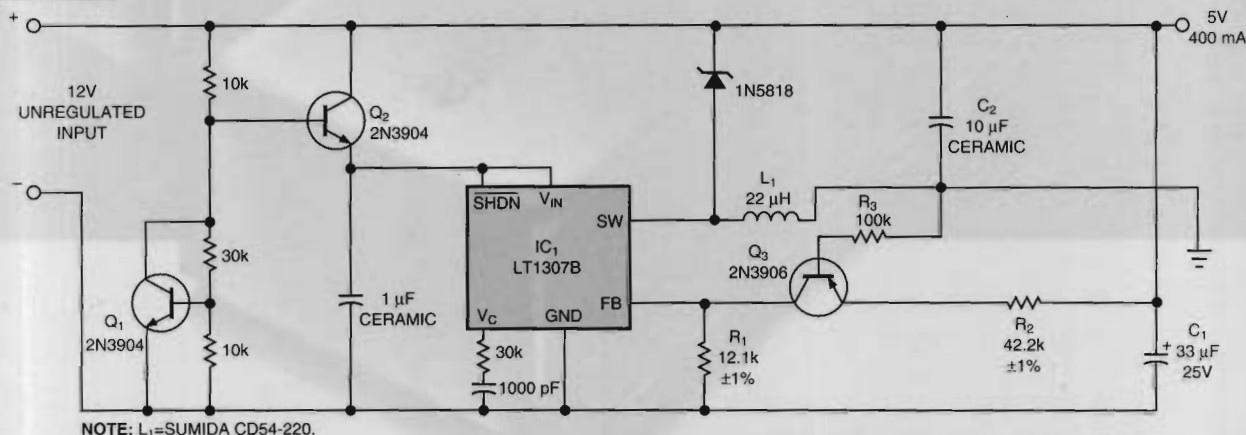
the cost advantage of a linear regulator. The circuit in Figure 1, a negative buck converter, delivers 5V at loads as high as 400 mA from a 7 to 25V input with peak efficiency of 85%. The circuit requires no heat sinking.

Because the LT1307B (IC<sub>1</sub>) is designed to operate with a low input voltage, you use Q<sub>1</sub> and Q<sub>2</sub> to form a simple pre-regulator, providing 1.9V to IC<sub>1</sub>'s V<sub>IN</sub> pin. The IC switches at 600 kHz; you can thus use a low-cost 22-μH inductor and a 10-μF ceramic output capacitor. You need Q<sub>3</sub> to level-shift the output voltage, because IC<sub>1</sub>'s feedback pin uses the negative input as a reference. Output ripple measures 10 mV p-p with a 400-mA load. Figure 2 shows the efficiency of the circuit; Figure 3 gives the response of a load step from 150 to 300 mA.

Input bypass capacitor C<sub>1</sub> encounters worst-case rms ripple current equal to half the output current; its ESR should be lower than 0.5Ω. During construction, keep R<sub>1</sub> through R<sub>3</sub> close to IC<sub>1</sub>'s FB pin and away from the SW pin to prevent undesirable coupling. Use a ground plane and keep the traces for the power components short and direct. Although the fact that the negative side of the wall cube is not grounded might seem unsettling, remember that the 9V wall cube floats. The circuit merely regulates the negative side, rather than the more conventional positive side. (DI #2079) **EDN**

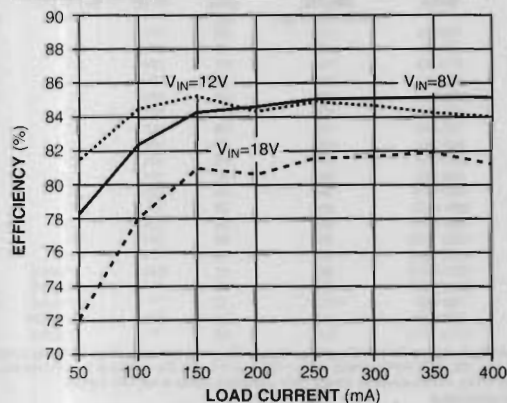
To Vote For This Design, Circle No. 313

FIGURE 1



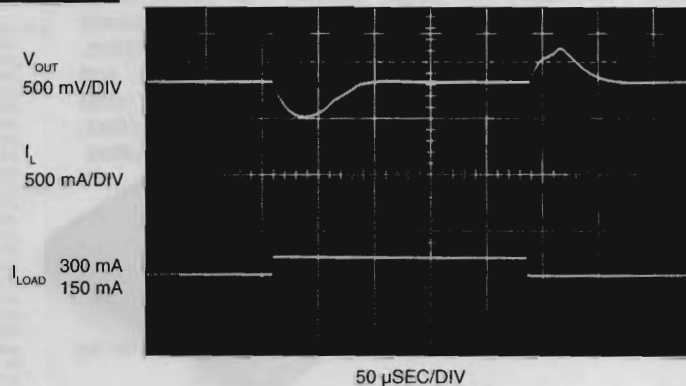
An 85%-efficient dc/dc converter eliminates the large, heavy heat sink you'd need in using a wall-cube adapter with a 5V linear regulator.

FIGURE 2



Efficiency of the circuit in Figure 1 remains much greater than 80% for most practical combinations of line voltage and load current.

FIGURE 3



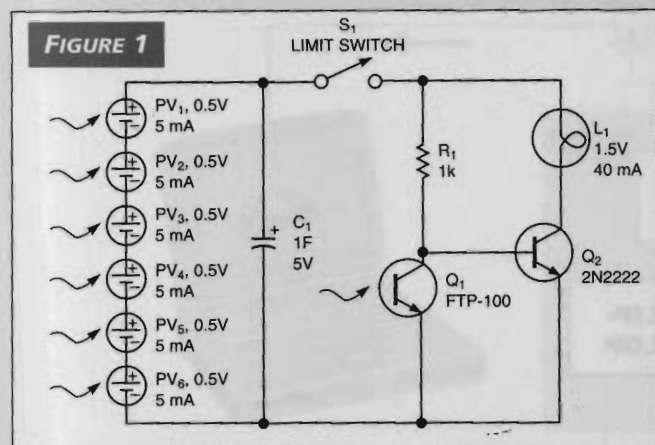
The output voltage of the circuit in Figure 1 sags and rises only approximately 300 mV and recovers in less than 50 μsec for a 150-mA current step in the load current.



# Solar cells implement low-cost illuminator

DENNIS EICHENBERG, PARMA HEIGHTS, OH

The advent of inexpensive solar cells and low-cost "ultracapacitors" makes it possible to develop an entirely solar-powered inspection illuminator (Figure 1). The illuminator is



**Why mess with short-lived, expensive batteries, when for about \$8 you can make a solar-powered mailbox illuminator that lasts a lifetime?**

useful in exterior locations having no convenient source of power but needing an occasional illumination source. A mailbox illuminator is a typical application for this circuit. A mailbox is located away from power sources; you usually open it once a day to inspect for deliveries. It's best to avoid the use of batteries in this application, because temperature extremes severely shorten battery life. The circuit in Figure 1 is inexpensive, compact, reliable, and rugged.

Six 0.5V solar cells, PV<sub>1</sub> through PV<sub>6</sub>, form a series combination to provide 3V to the circuit under normal illumination. A 1F ultracapacitor connects directly in parallel with the solar cells. The 5-mA solar-cell current slowly charges the capacitor to 3V. Switch S<sub>1</sub> closes automatically whenever you open the mailbox door. The closure provides 3V to the remainder of the circuit. Phototransistor Q<sub>1</sub> keeps transistor Q<sub>2</sub> off if exterior light exists. This feature prevents C<sub>1</sub> from discharging unless it's dark out. When it is dark out, Q<sub>1</sub> turns off, and Q<sub>2</sub> turns on to provide approximately 10 sec of illumination from lamp L<sub>1</sub>. The parts are readily available from most distributors, and total parts cost is approximately \$8. (DI #2080)

EDN

To Vote For This Design, Circle No. 314

# Digitally control gain over a ±40-dB range

MARK SHILL, BURR-BROWN CORP, TUCSON AZ

Digitally controlled amplifiers typically take the form of programmable-gain amplifiers (PGAs). Though useful for many applications, PGAs have the disadvantage of large, discrete gain steps, such as gains of 1, 2, 4, and 8. For higher resolution gain steps, you must use a different approach. The circuit in Figure 1 can digitally control an amplifier's gain over a ±40-dB range. The circuit has a programmable-gain resolution of 1.25 dB and can attenuate or amplify the input signal, depending on the digital code you apply. You could use this high-resolution PGA as the front end of an ADC and thus obtain increased dynamic range. The circuit is also useful as a digitally controlled audio pre-amplifier.

The circuit is based on the VCA610 voltage-controlled amplifier, IC<sub>3</sub>. This IC amplifies or attenuates the differential signal between input pins 1 and 8, depending on the voltage you apply to the V<sub>C</sub> gain-control, Pin 3. The equation relating the gain of the VCA610 to V<sub>C</sub> is  $A=10^{-(V_C+1)}$ . V<sub>C</sub> can vary linearly over the range of 0 to -2V, representing an amplifier-gain range of -40 to +40 dB,

respectively. The circuit uses a 6-bit digital word to set the gain of the VCA610. A simple binary DAC converts the digital gain-control code to the corresponding V<sub>C</sub> control voltage.

The DAC comprises op-amp IC<sub>2</sub>, binary-weighted resistors R<sub>1</sub> through R<sub>6</sub>, and feedback resistor R<sub>7</sub>. IC<sub>2</sub>, configured in inverting mode, drives IC<sub>3</sub>'s gain-control pin. IC<sub>1</sub>, a CMOS noninverting driver, buffers the digital input code and provides simple reference-voltage levels of 0 and 5V for the binary-weighted DAC resistors. Each of IC<sub>1</sub>'s outputs typically has an output impedance lower than 50Ω to either ground

or the 5V supply. To minimize the DAC resistors' loading effect on IC<sub>1</sub>'s outputs, the values for R<sub>1</sub> through R<sub>6</sub> are such that the most-significant-bit (MSB) resistor, R<sub>1</sub>, is 10 kΩ, and resistors R<sub>2</sub> through R<sub>6</sub> are binary multiples of 10 kΩ.

To further ensure that IC<sub>1</sub> can pull up the MSB resistor, R<sub>1</sub>, to near 5V, two outputs connect in parallel to provide increased drive. If you use ±1% or better resistors for R<sub>1</sub> through R<sub>6</sub>, the DAC produces a monotonic output at 6 bits. IC<sub>2</sub>

TABLE 1—GAIN AND V<sub>C</sub> VS DIGITAL INPUT

| DAC code | V <sub>C</sub> (V) | Gain (V/V) | Gain (dB) |
|----------|--------------------|------------|-----------|
| 000000   | 0                  | 0.01       | -40       |
| 010000   | -0.5               | 0.1        | -20       |
| 100000   | -1                 | 1          | 0         |
| 110000   | -1.5               | 10         | 20        |
| 111111   | -1.969             | 86.6       | 38.75     |

has a maximum offset voltage of  $\pm 0.5$  mV and has FET inputs whose bias currents cause no additional offset error for the DAC.  $R_7$  is one-fifth of  $R_6$ , or 2 k $\Omega$ , setting the 0 to -2V (actually, 0 to -1.96875V) transfer range of the DAC. The positive full-scale gain of the amplifier is 40 dB minus one least significant bit (LSB), or 38.75 dB. You can adjust the value of  $R_7$  to change the range of the DAC, as long as the voltage to the  $V_C$  pin remains approximately 0 to -2V.

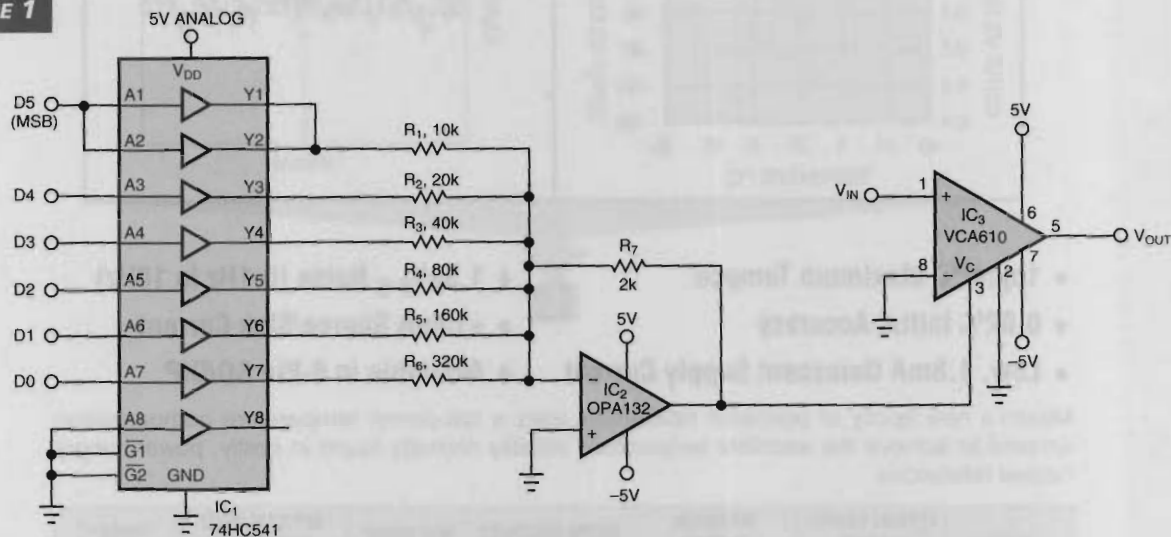
Table 1 shows the relationship between the digital code to the resistor DAC and  $IC_3$ 's control voltage and gain. For a 6-bit DAC, the gain-step increment, or least significant bit (LSB,) is 1.25 dB ( $LSB=80\text{ dB}/2^6$ ). For increased accuracy and

resolution, you can use a 12-bit DAC (Figure 2). Connecting pins 2, 3, and 9 configures DAC  $IC_1$  for an output range of 0 to 10V. The DAC813 has internal data latches for the 12-bit digital-input code, which you write to the DAC by momentarily taking the WR signal low. The circuit uses only the first 10 bits of the DAC, providing a gain-step resolution of 0.078 dB ( $LSB=80\text{ dB}/2^{10}$ ), or approximately 1%. Op-amp stage  $IC_2$  inverts and attenuates the 0 to 10V range of the DAC to a corresponding range of 0 to -2V. (DI #2084)

EDN

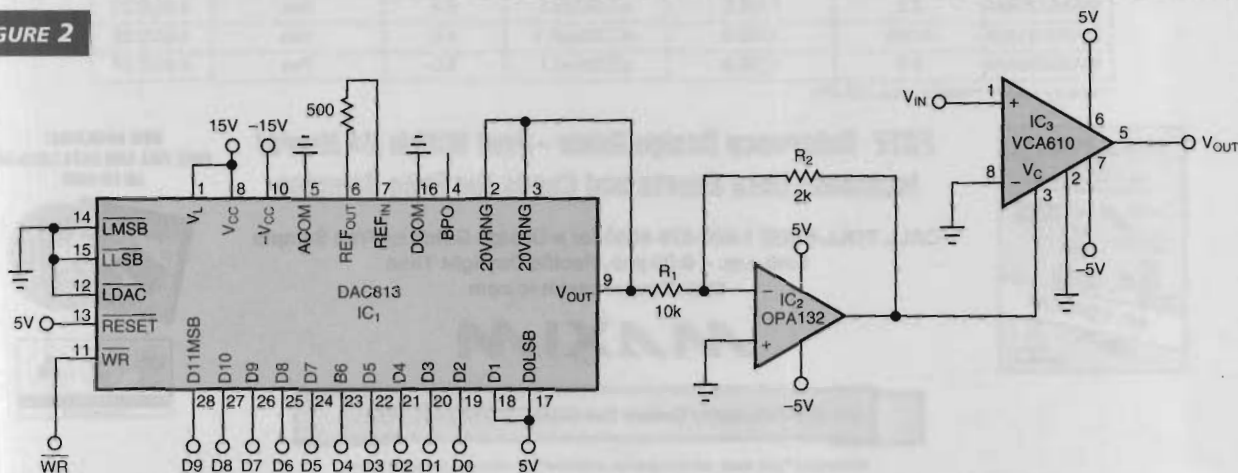
To Vote For This Design, Circle No. 315

FIGURE 1



A simple DAC and a voltage-controlled amplifier allow you to control gain over an 80-dB dynamic range.

FIGURE 2



Using 10 bits of a 12-bit DAC quadruples the gain resolution of the circuit in Figure 1.

# Simple regulator monitors its input voltage

LARRY SUPPAN AND LUONG HUYNH, MAXIM INTEGRATED PRODUCTS, SUNNYVALE, CA

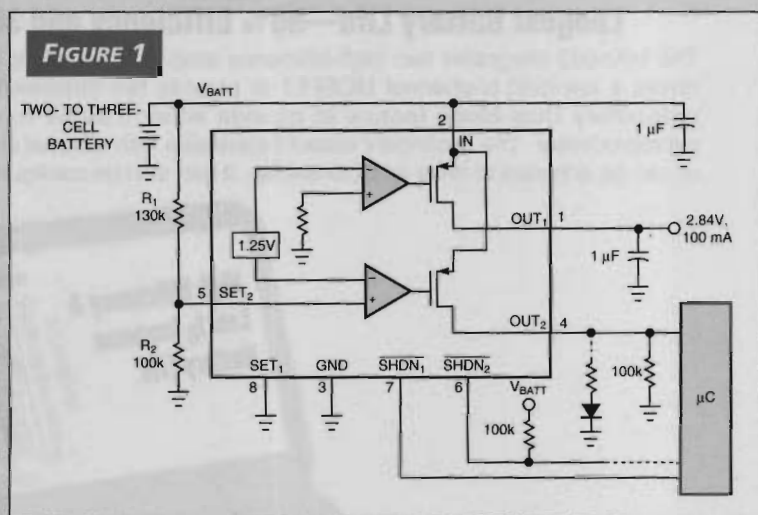
Two- and three-cell portable systems, such as medical sensors, often monitor their battery input to obtain an early warning of a loss of battery voltage. Typically, this warning is a digital signal that a comparator generates and then sends to the microcontroller. The circuit in Figure 1 presets one side of a dual linear regulator to generate 2.84V at 100 mA. The other side operates open loop, as a comparator, to generate the low-battery warning. Both sides are capable of delivering 100-mA output current. Resistors  $R_1$  and  $R_2$  determine the low-battery threshold, according to

$$V_{LBT} = \frac{V_{SET}(R_1 + R_2)}{R_2} = \frac{1.25(130k + 100k)}{100k} = 2.875V.$$

(DI #2089)

To Vote For This Design, Circle No. 316

EDN



This simple circuit generates a 2.84V, 100-mA supply voltage and monitors its own input voltage.

## Basic routine simplifies factoring

ALAN LAND, KEYSTONE DIGITAL CO, PITTSBURGH, PA

Logarithms greatly simplify mathematical operations. Factoring, however, presents a problem: Pocket calculators are clumsy when it comes to that operation. The program factor.bas (Listing 1) is a convenient alternative if you want to obtain results in 3 minutes or less (that is, turn on the computer, put the disk in the b: drive, select "qbasic," run the program, enter the number, obtain results, and go back to work).

The input range is integers-only, from 2 to 2,147,483,647. The largest prime number is 131,071, the 12,251st prime. The program produces complete or incomplete factorizations. Incomplete factorizations are always correct but have a factor greater than 131,071. A complete factorization always appears with all terms in parentheses; for example,

$$120 = (2 \cdot 3) \cdot (3 \cdot 1) \cdot (5 \cdot 1).$$

The incomplete factorizations appear as

$$65,289,755 = 567,737 \cdot (5 \cdot 1) \cdot (23 \cdot 1).$$

Yet a third format is

$$567,737 = (567,737) \cdot$$

The third format indicates that the number is prime. Within the range that the program cites, enter only the integer—not any symbols, such as commas or decimal points. The range,  $2^{31}-1$ , and the number of primes, 12,251, are based on QBasic's long-integer array mechanism. It just so happens that the 12,251st prime is also  $2^{17}-1$ . Make sure that

### LISTING 1—BASIC ROUTINE FOR FACTORING

```
factor: CLS : LOCATE 12, 37: PRINT " WAIT! "
DIM p&(12250): DIM b&(15): DIM e&(15)
p&(0) = 2: a& = 1: x& = 3: p&(1) = 3
DO: k& = 1: x& = x& + 2: n = SQR(x&)
a: IF x& MOD p&(k&) = 0 THEN GOTO c
IF p&(k&) > n THEN GOTO b
k& = k& + 1: GOTO a
b: a& = a& + 1: p&(a&) = x&
c: LOOP UNTIL x& > 131071
d: CLS : ERASE b&, e&: e& = 1: a& = 0: k& = 0
INPUT "Enter integer: limit is 2147483647 ": x&: w& = x&
DO
e: IF w& MOD (p&(k&) ^ e&) < 0 THEN GOTO f
ON ERROR GOTO h
e& = e& + 1: GOTO e
f: e& = e& - 1: IF e& = 0 THEN GOTO g
b&(a&) = p&(k&): e&(a&) = e&: a& = a& + 1
w& = w& / (p&(k&) ^ e&)
IF w& = 1 THEN GOTO i
g: k& = k& + 1: e& = 1
LOOP UNTIL k& > 12250
h: PRINT x&: "=": w&: "": GOTO j
j: k& = 0: IF a& = 0 THEN GOTO l
PRINT "(" : b&(k&): "": e&(k&): "":
IF k& < a& - 1 THEN PRINT "":
IF k& = a& - 1 THEN GOTO l
k& = k& + 1: GOTO k
l: PRINT "Enter 1 to exit, hit ENTER key to continue": a&
IF a& = 1 THEN END "FACTOR.BAS by A. M. Land"
GOTO d
```

you do not use a tracer on this program; you need to reset to get out of the loop. The program takes approximately 1 minute to load all the primes. With the tracer on, loading might take about a day. (You can download Listing 1 from EDN's Web site, [www.ednmag.com](http://www.ednmag.com). At the registered-user area, go into the Software Center to download the file from DI-SIG, #2083.) (DI #2083)

EDN

To Vote For This Design, Circle No. 317